Electron Cooling R&D at the Relativistic Heavy Ion Collider

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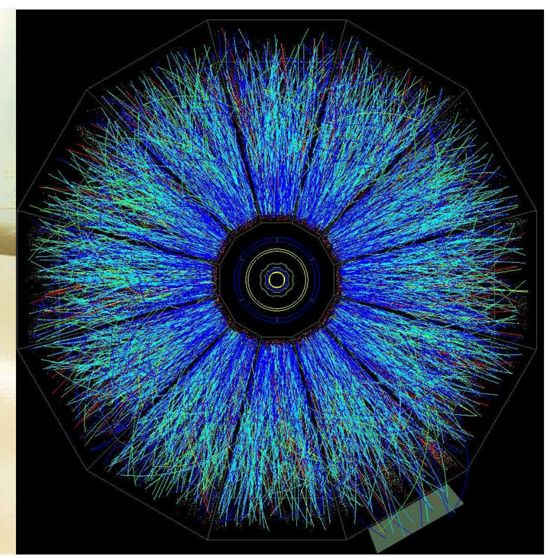
Collider-Accelerator and Physics Departments,
Brookhaven National Laboratory

Research topics:
- Beam dynamics,
- CW Photoinjector,
- High current ERL,
- Precise Solenoid,
- Cooling simulation.

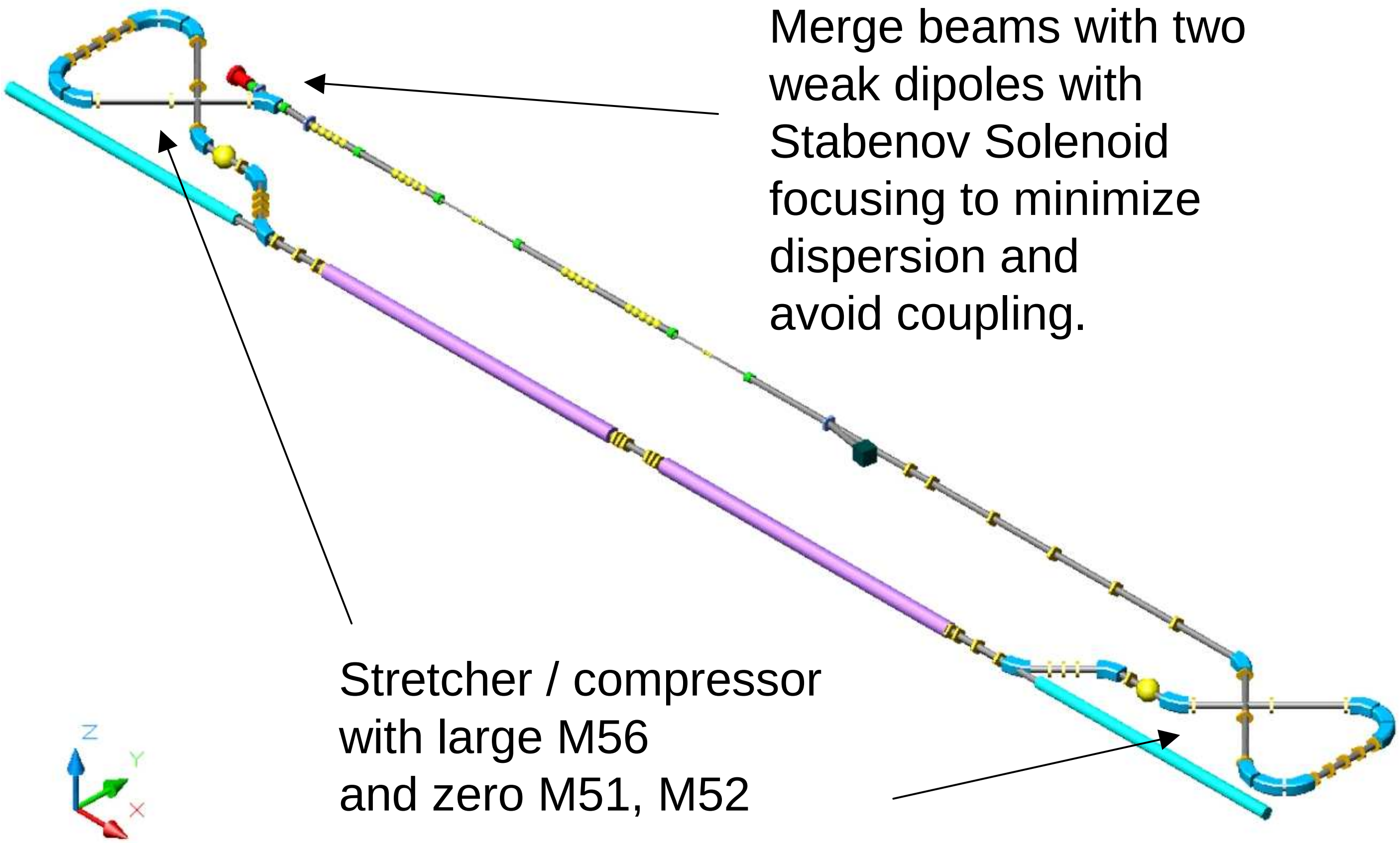


RHIC

Need for R&D

- The 54 MeV electron beam is about 150 times higher than any existing cooler.
- We need a very efficient accelerator.
- The electron beam needs to be “cold”, and at a high current (>0.1 A).
- Issues of bunched beams in injector, magnetized beam transport and cooling.
- A very long, super-precise solenoid is needed (30 m long, 1 Tesla, $8x10^{-6}$ error)

Beam Dynamics



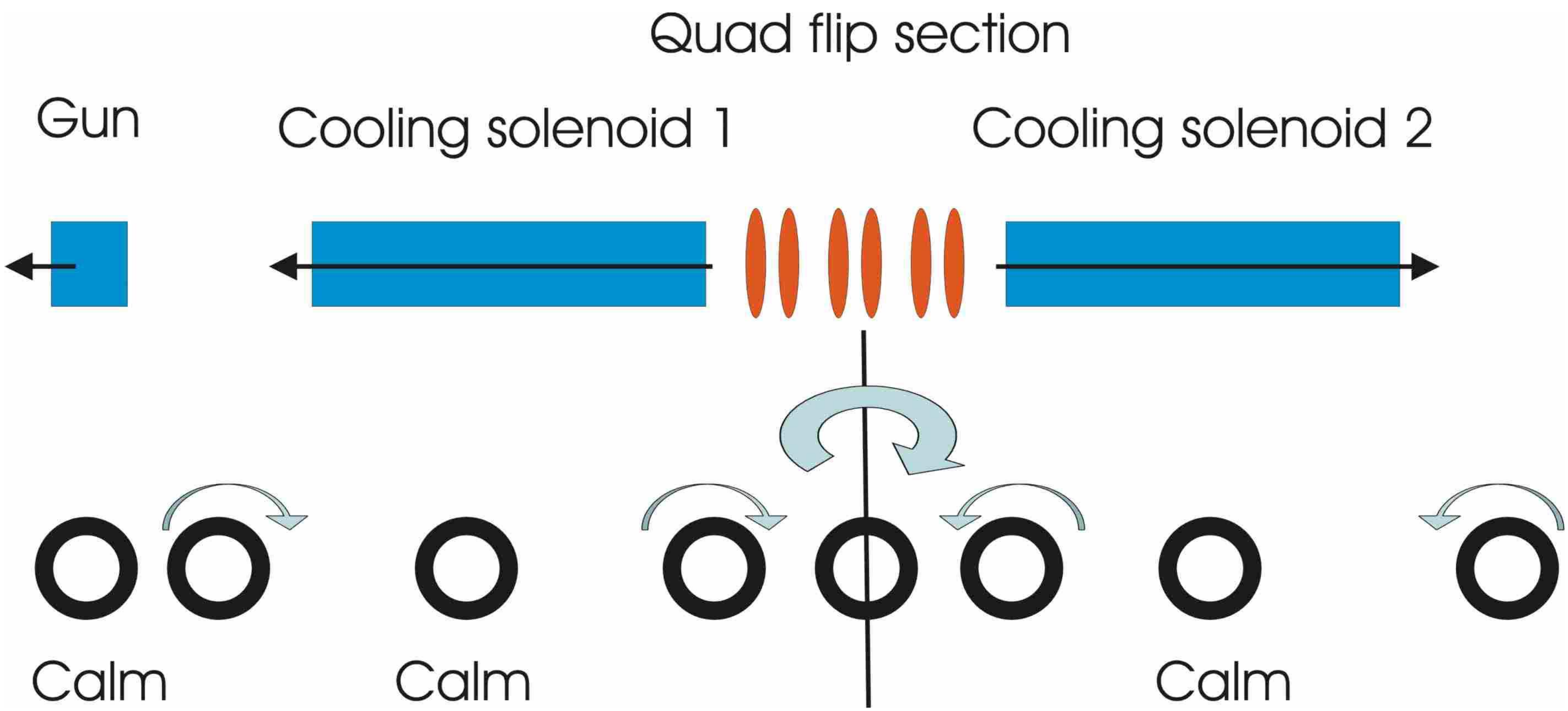
Merge beams with two weak dipoles with Stabenov Solenoid focusing to minimize dispersion and avoid coupling.

Stretcher / compressor with large M56 and zero M51, M52

Use two solenoids with opposing fields to eliminate coupling in the ion beam.
A quadrupole matching section between the solenoids maintains magnetization.

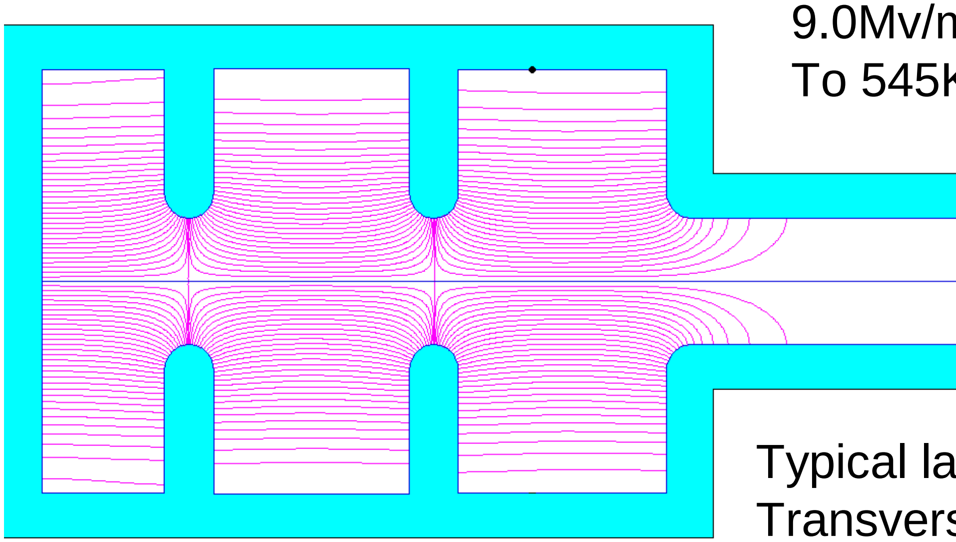
Joerg Kewisch

Beam Dynamics



Beam Dynamics – start from the photoinjector

- Working on start-to-end simulation with PARMELA.
- Magnetized beam transport with emittance correction



9.0Mv/m on cathode correspond
To 545KW power dissipation in cavity.

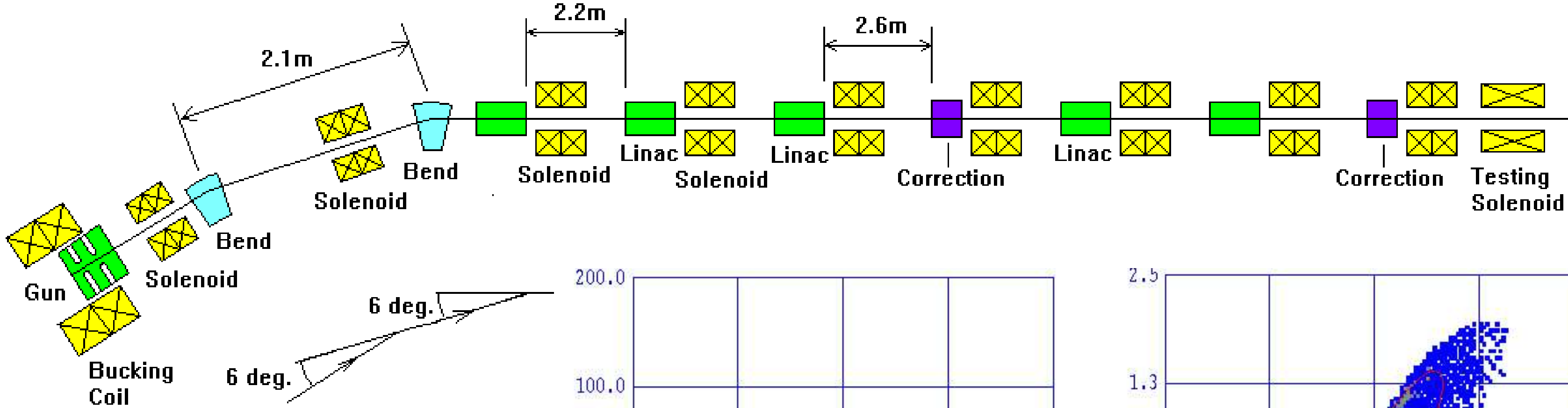
Typical laser distribution:
Transverse uniform, R = 15 mm.
Longitudinal Gaussian, FWHM = 4 deg.

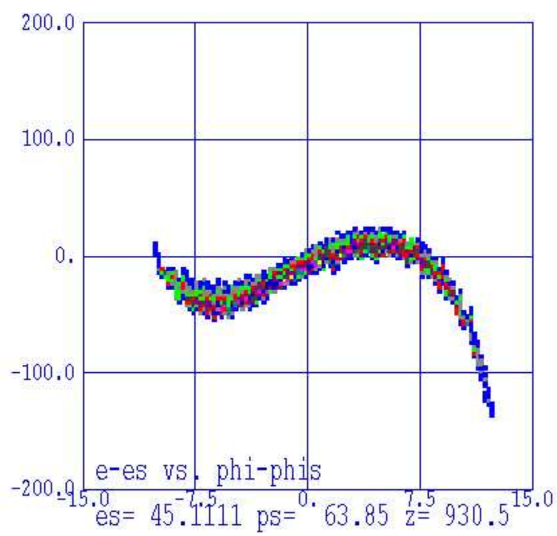
Xiangyun Chang

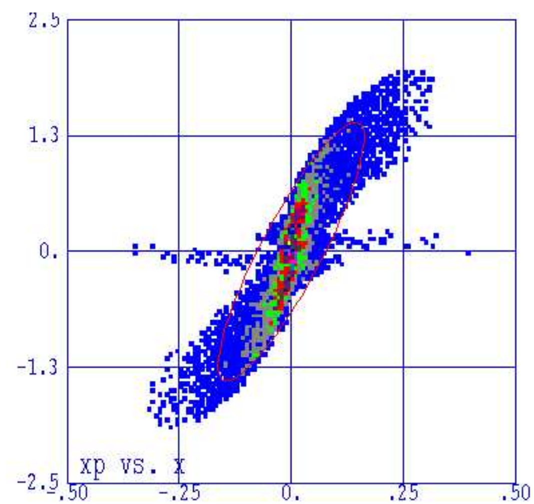
Beam Dynamics – non-magnetized beam

In simulations: Charge = 10 nC, Lunch phase = 30 deg.

Non-magnetized beam: Achieved **ε_X=23.8mm.mrad, ε_Z=114.5deg.kev**



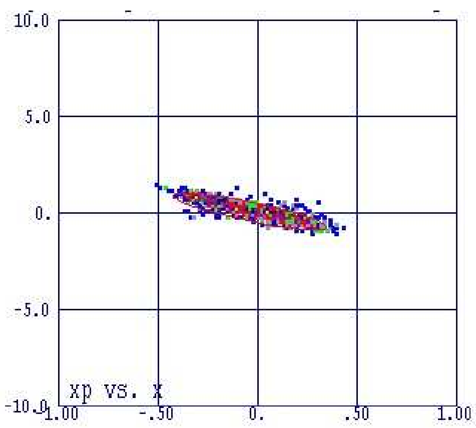


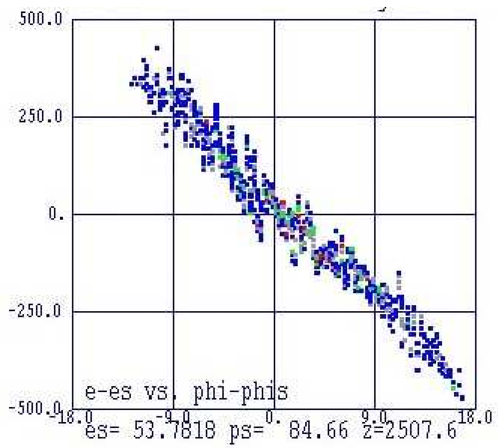


Xiangyun Chang

Beam Dynamics – magnetized beam

The emittance correction of magnetized beams has subtle aspects.
Must satisfy preservation of magnetization for each beam slice.

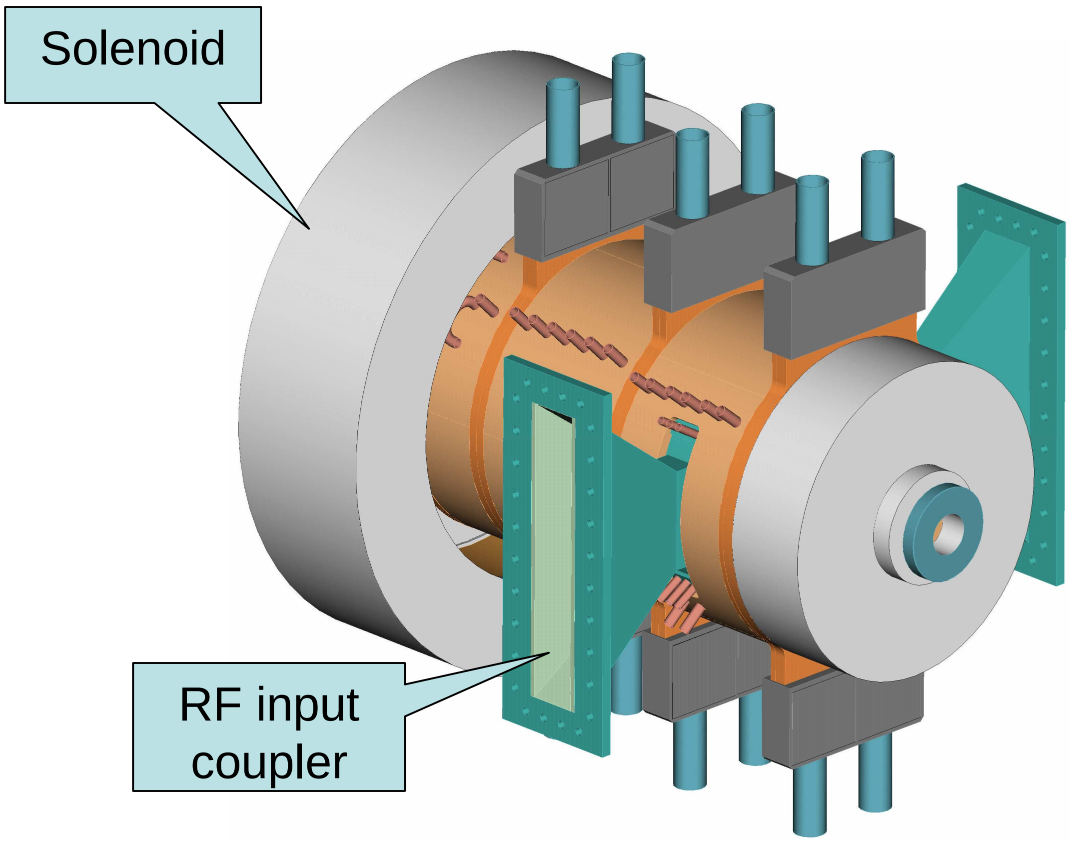




Results without proper emittance correction:
ε_x=51 mm.mr, ε_y=60 mm.mr, ε_Z=285 deg.kev
Acceptable results, but we expect improvements in emittance.
Following just bunch rotation we obtain minimum dE/E=1.5×10^{-4}
Full bunch length 3.5 cm. Question: Do we need to stretch the bunch?

Xiangyun Chang

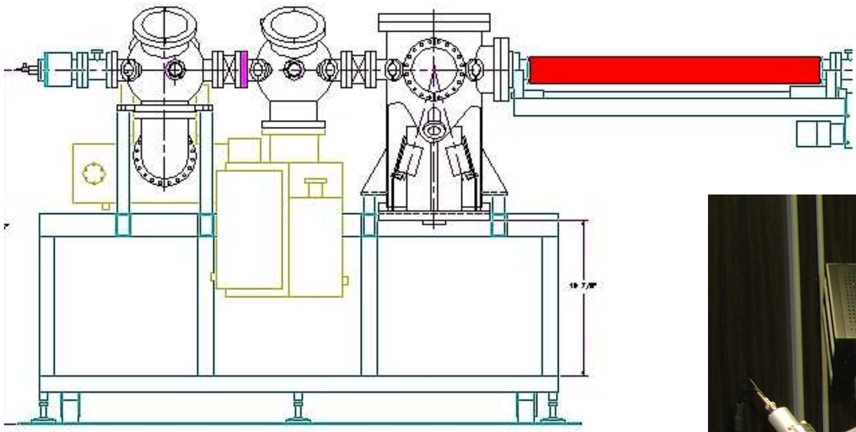
Photoinjector -
New 703 MHz CW Photoinjector



LANL and Advanced Energy Systems

New 703 MHz
CW Photoinjector
Under design

Photoinjector - CsK_2Sb efficient photocathode

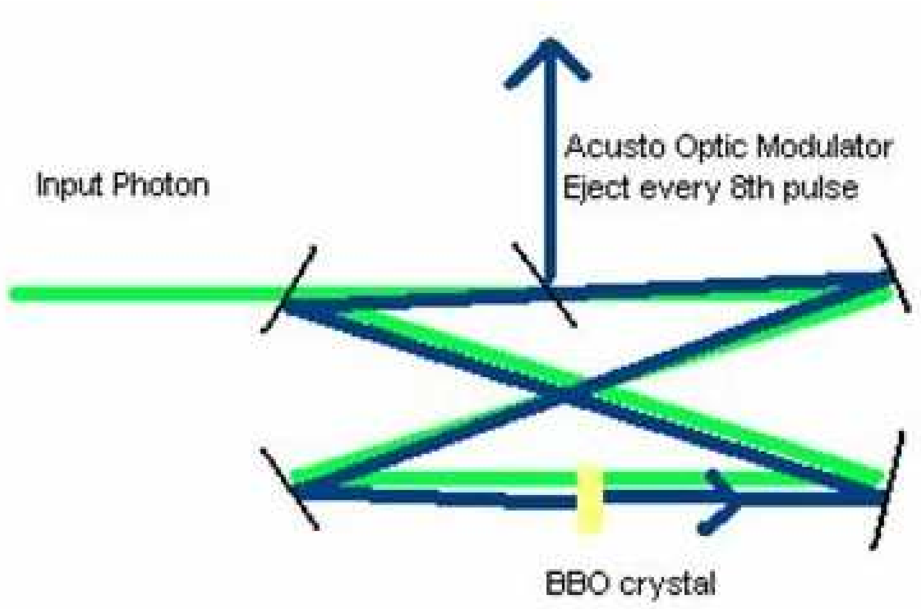


New UHV photocathode preparation system

Triveni Srinivasan-Rao, Andrew Burrill, Dave Dowell

Photoinjector – laser technology

We are developing an efficient frequency doubler – pulse-rate reducer.
The principle is coherent harmonic generation from IR to green
in a BBO crystal in a bowtie recirculating cavity.

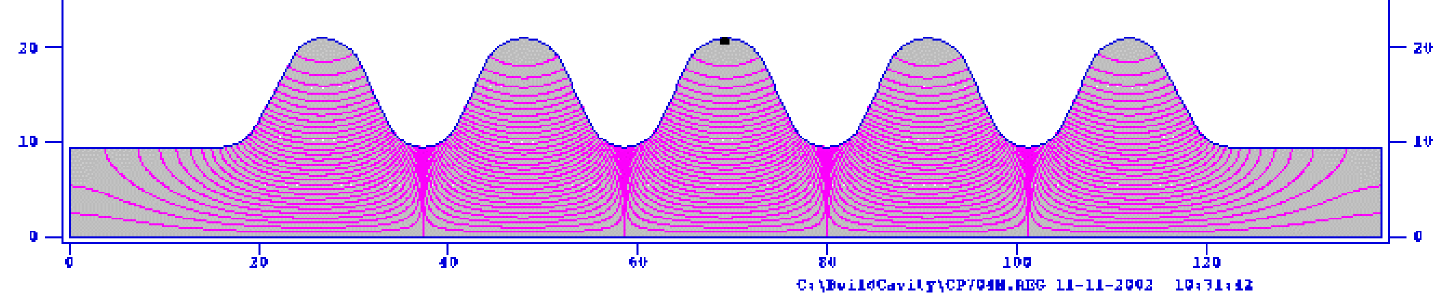


Triveni Srinivasan-Rao, Andrew Burrill

Energy Recovery Linac

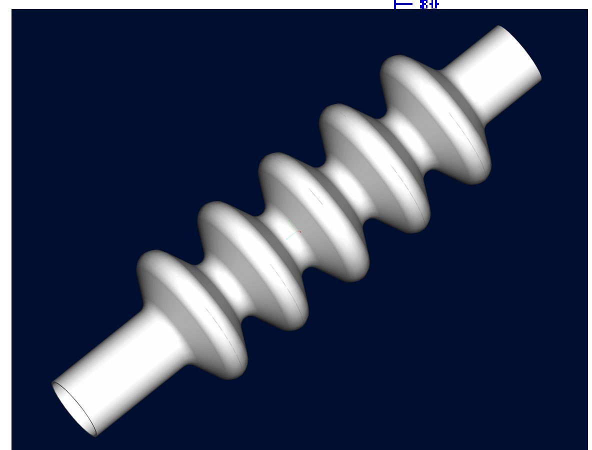
- Need to develop a cavity for high average current, large-charge bunches (HOM!)
- Frequency choice to match JLAB chemical cleaning capability, eRHIC harmonic and availability of high RF power for gun.
- Optimized for best possible damping of HOMs, following Cornell SR cavity design, adapted for a multi-cell cavity.

Energy Recovery Linac – large bore (19 cm diameter)



G	240	Ω
R/Q	710	Ω
Q_{bcs}	4.9	10^{10}
E_p/E_a	2.1	
H_p/E_a	5.94	mT/MV/m

FE modeling for acoustics



Carlo Pagani, Paolo Pierini

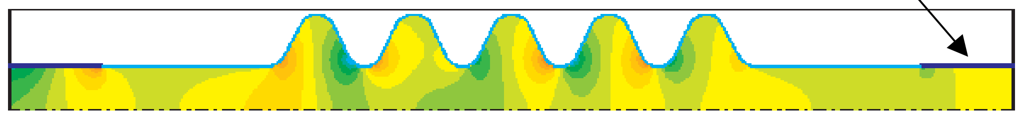
Energy recovery Linac - loss factor

Given 6×10^{10} electrons per bunch, σ=1.4 mm / 2.7 mm, bunch repetition frequency 28.2 MHz and ERL mode. ABCI calculation of loss factor.

Cavity (single)	TESLA 1.3 GHz	New 0.7 GHz
K_l (V/pC)	7.8	1.2
Power (kW)	39.6	6.6
Energy spread	30×10^{-4}	5×10^{-4}

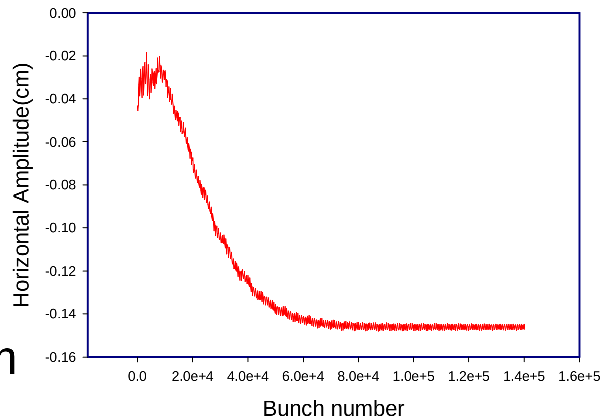
Energy Recovery Linac – beam breakup threshold by TDBBU

Ferrite absorber



Electromagnetic modes calculations and beam break-up

TDBBU, RHIC e-cooler
4x700MHz cavities with ferrite absorbers
I = 1000mA



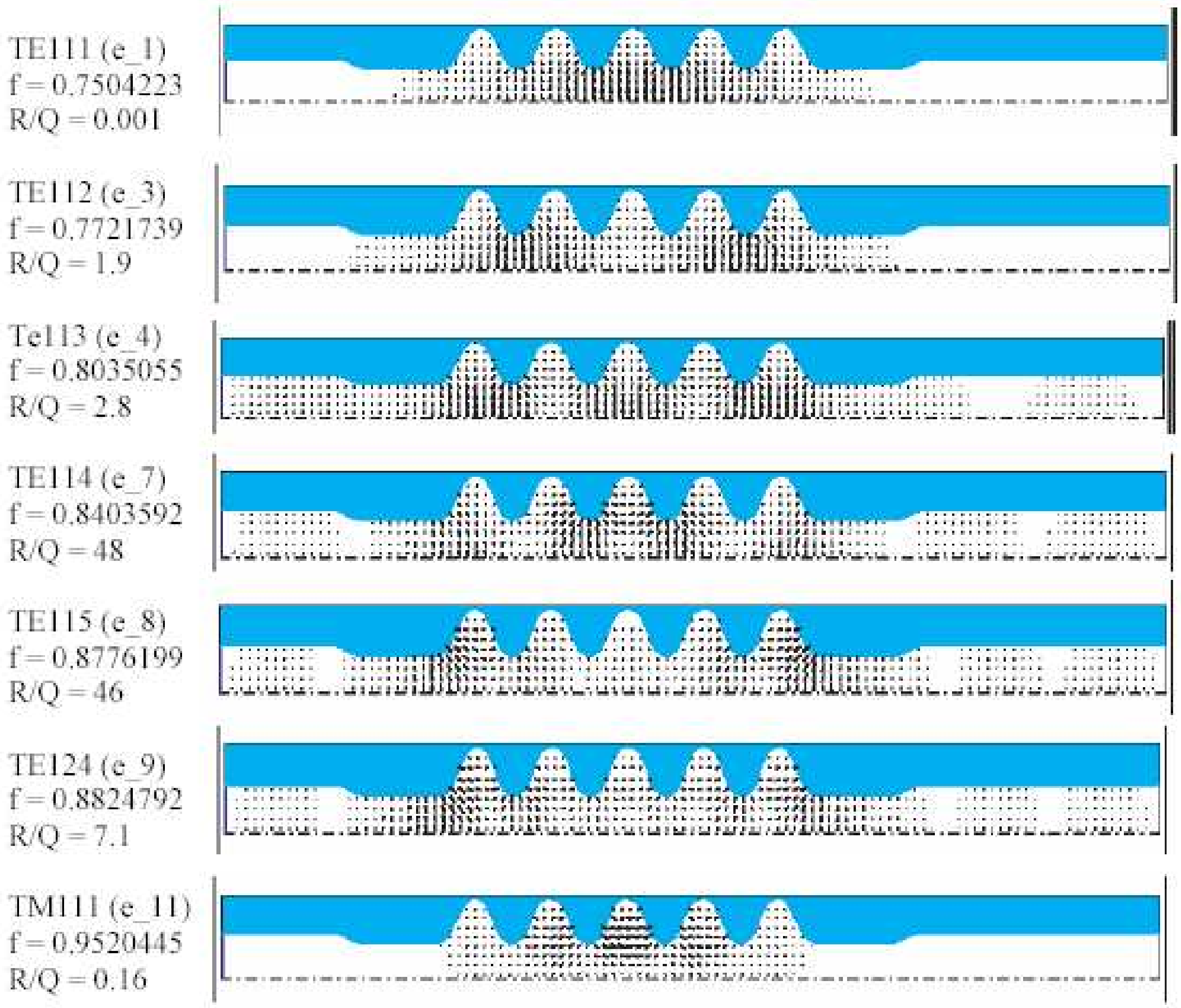
1 mm

0.1 second

1 ampere!

Dong Wang – **see TPAB046**

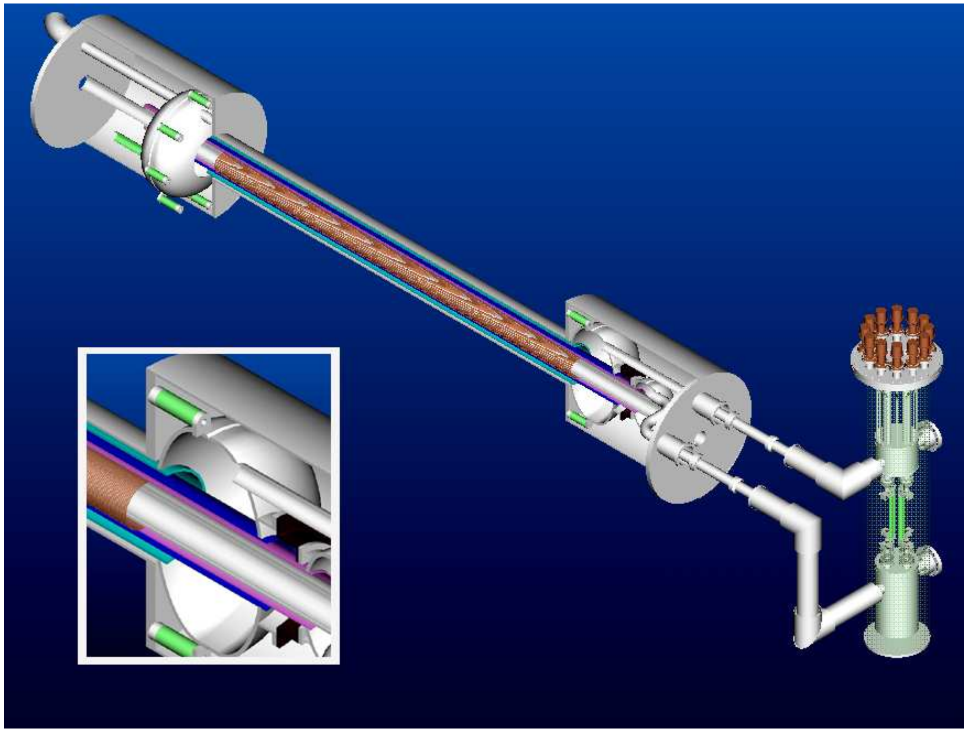
The electric field pattern of some dipole HOM
(by MAFIA)



Yongxiang Zhao

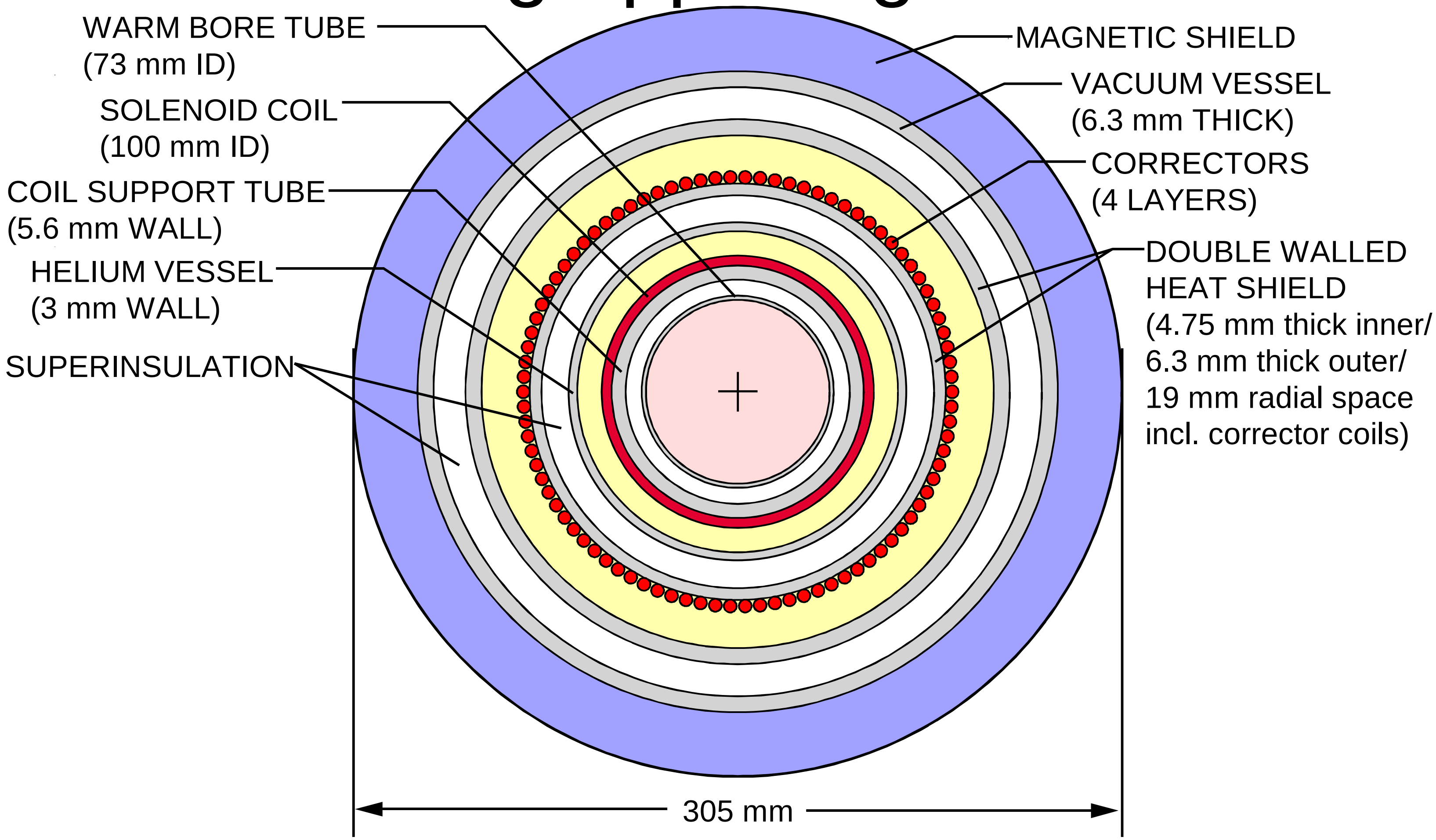
The Electron Cooler Solenoid – prototype to be constructed

A 100 feet long superconducting solenoid magnet
with a precision of a few parts per million!



RHIC

Superconducting Solenoid – Two 13 m long opposing 1T solenoids

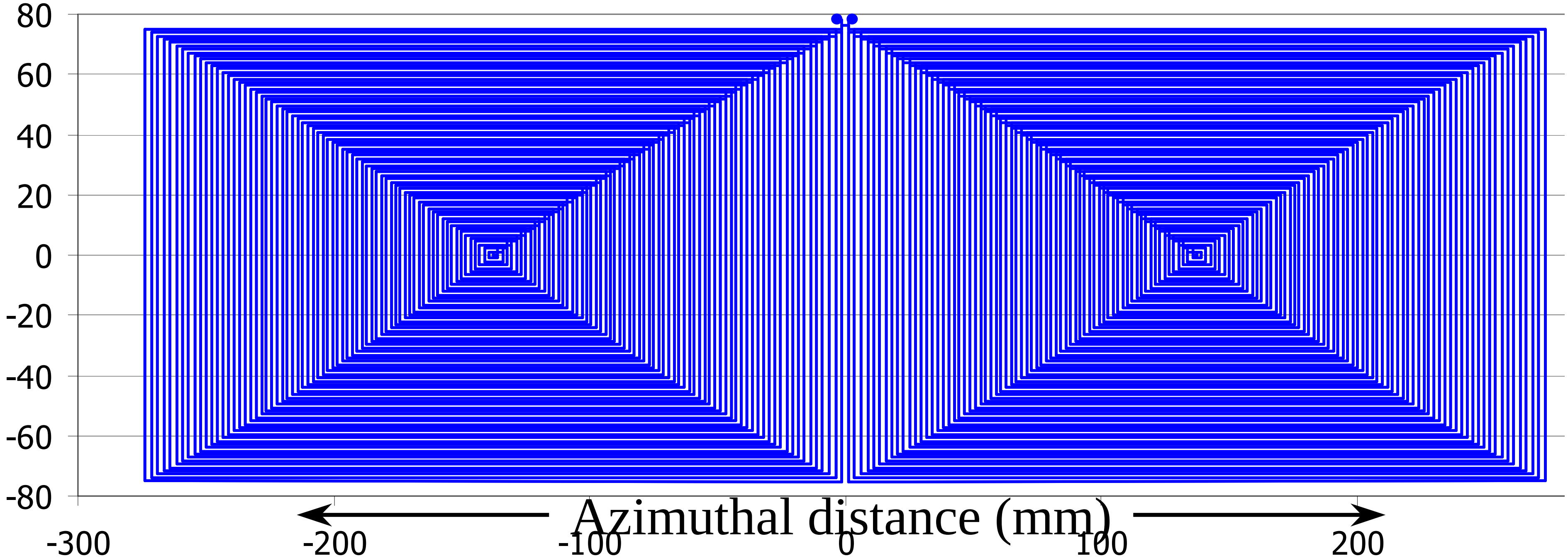


CROSS SECTION OF ELECTRON COOLER SOLENOID FOR RHIC

RHIC

Animesh Jain

Superconducting Solenoid – wrap-around printed correctors



175 mm diameter; 150 mm length; 68 turns/layer

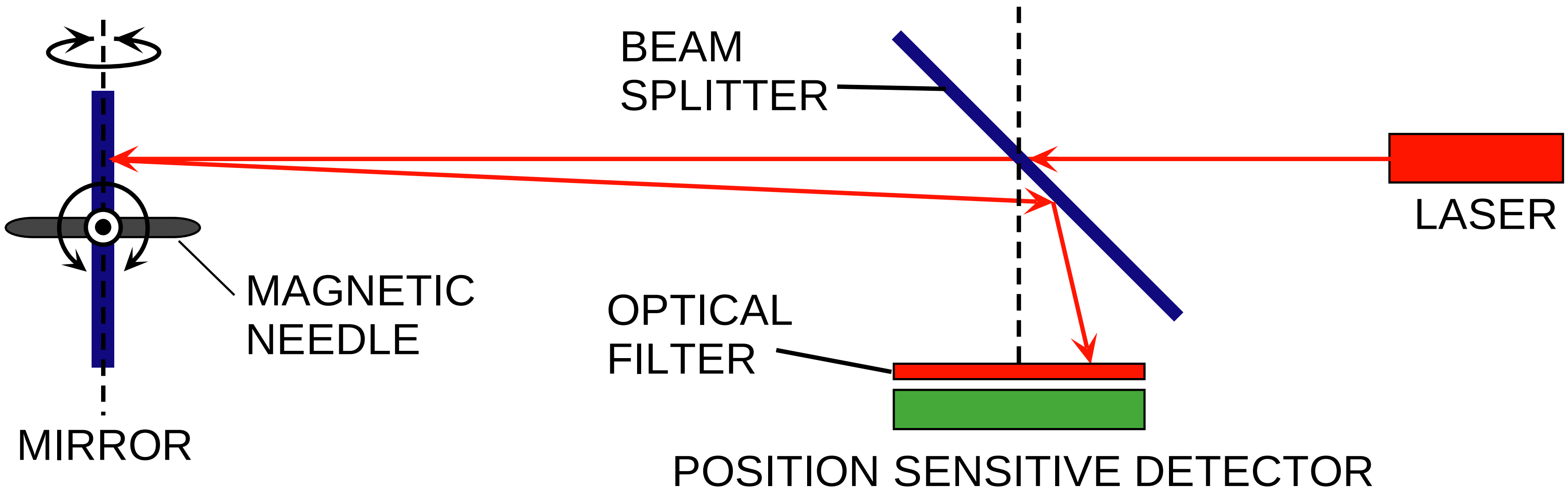
0.9 mm wide patterns;   0.2 mm gap between lines; 2 layers

~ zero integral harmonics 1.2×10^{-3} T at 2 A

RHIC

Animesh Jain,
following W.W. Zhang, et al., PRST-AB **3**, 122401 (2000)

Superconducting Solenoid - magnetic measurements



(Animesh Jain, Based on *C. Crawford et al.*, *FNAL and BINP*, *Proc. PAC'99*, *p. 3321-3*)

Expected resolution < 10^{-5} radian.

RHIC

Superconducting Solenoid – simulation of field correction

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B_y Error data;20 harmonics; Lambda=100mm to 2 meters; 6.5m long solenoid; ~6.6m long corrector
2 families; Dipole06a;b; 150mm patterns. 160mm spacing; 80mm offset for second layer; No extra gaps.

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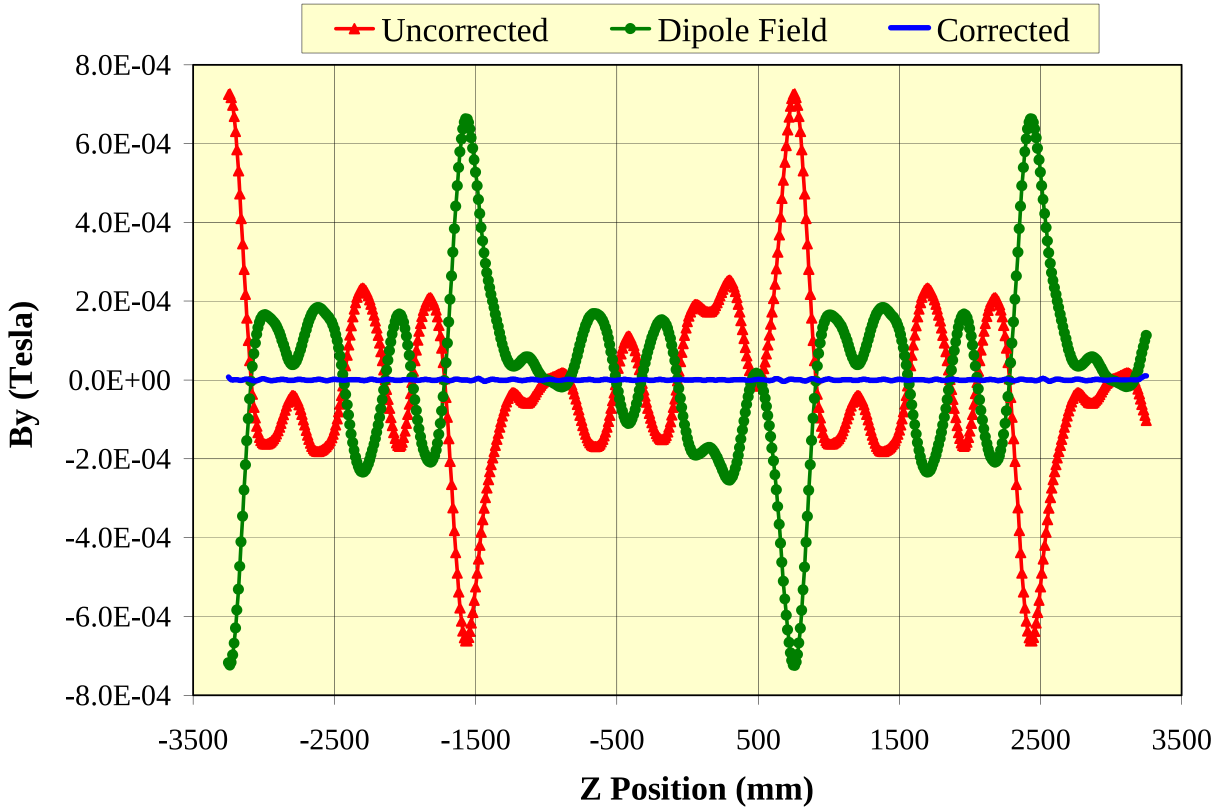
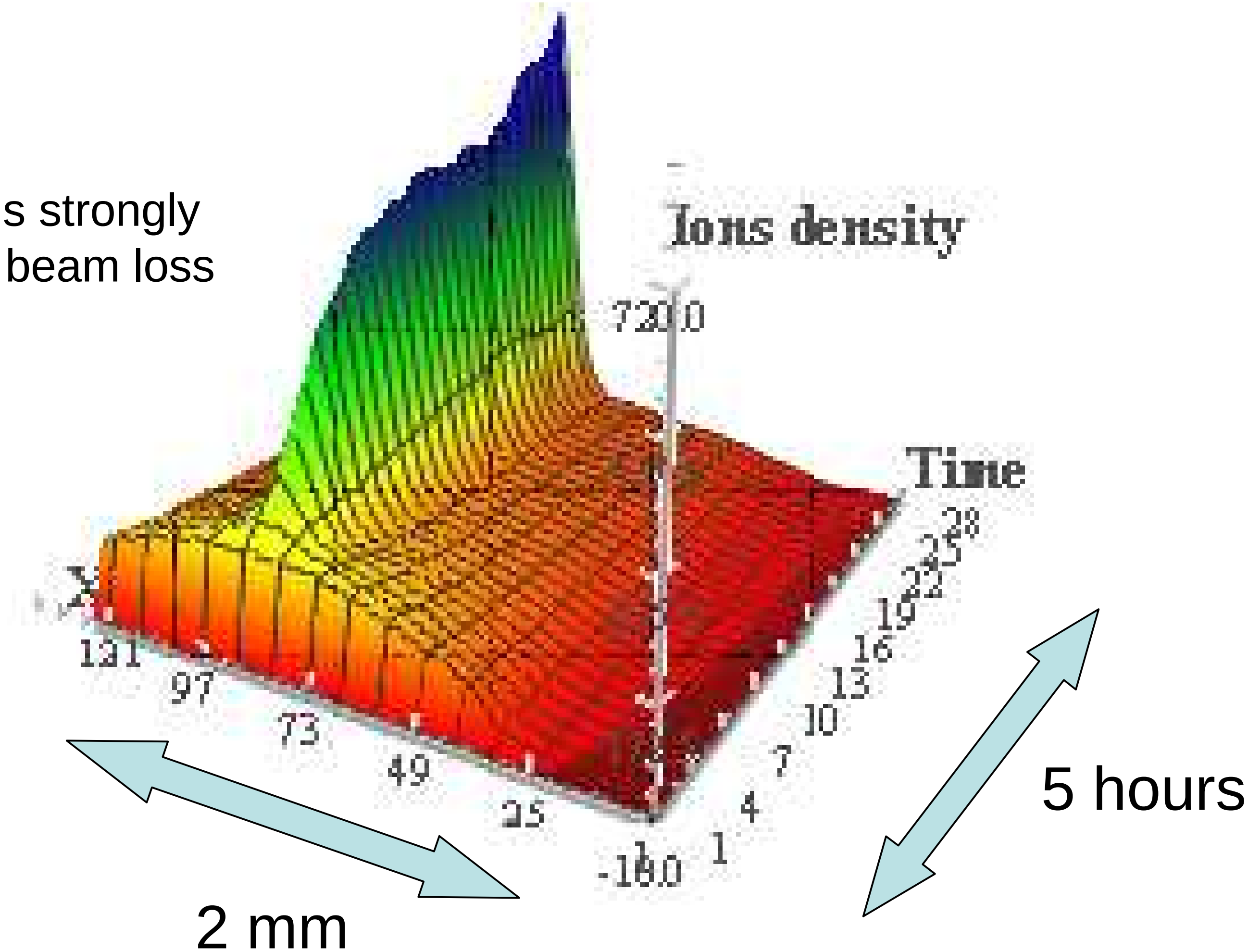


Simulated Data

Animesh Jain

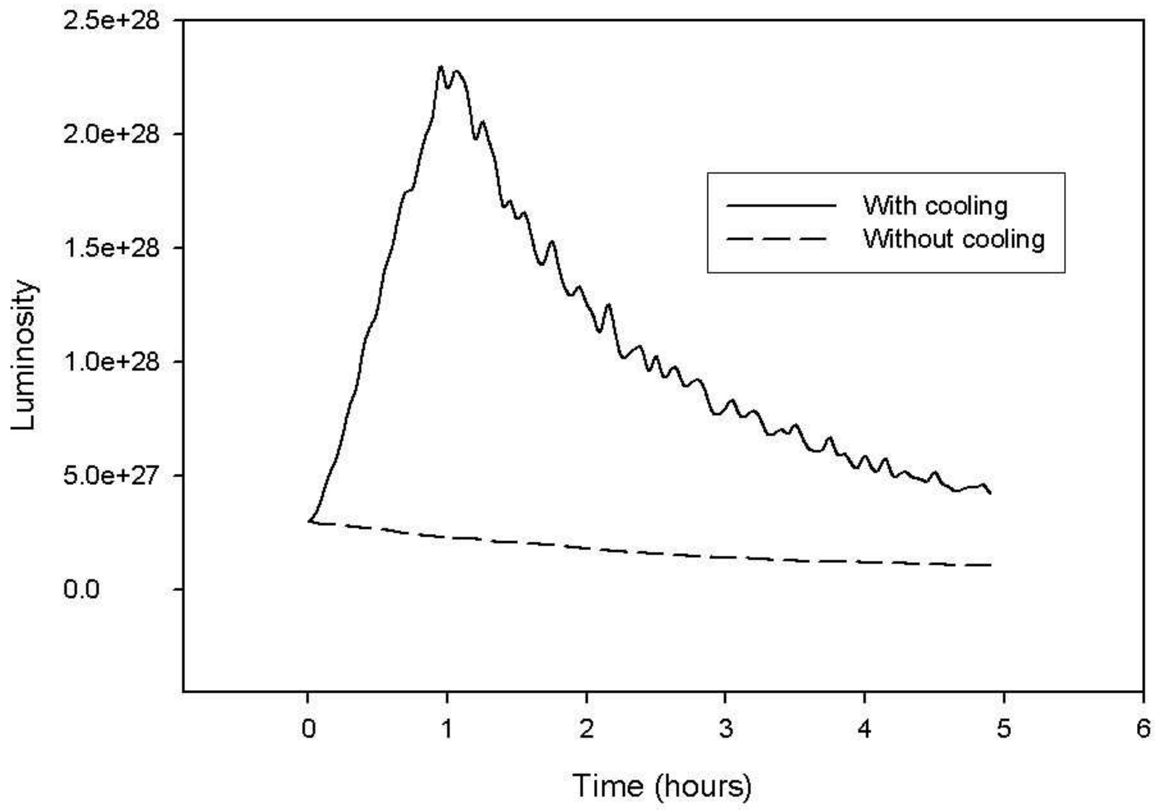
Cooling Simulations – SIMCOOL evolution of distribution

The evolution is strongly
Dependant on beam loss



Vasily Parkhomchuk

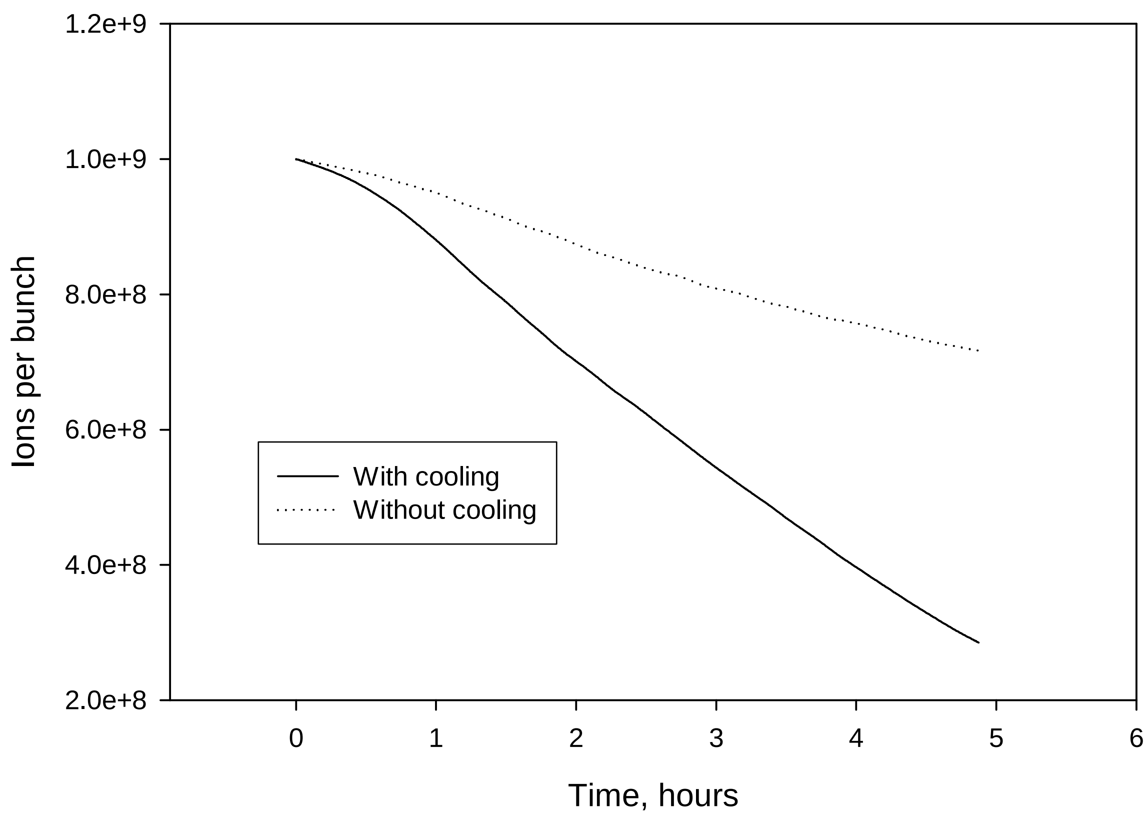
Cooling Simulations – SIMCOOL luminosity for gold



Vasily Parkhomchuk

Cooling Simulations – SIMCOOL particle loss for gold

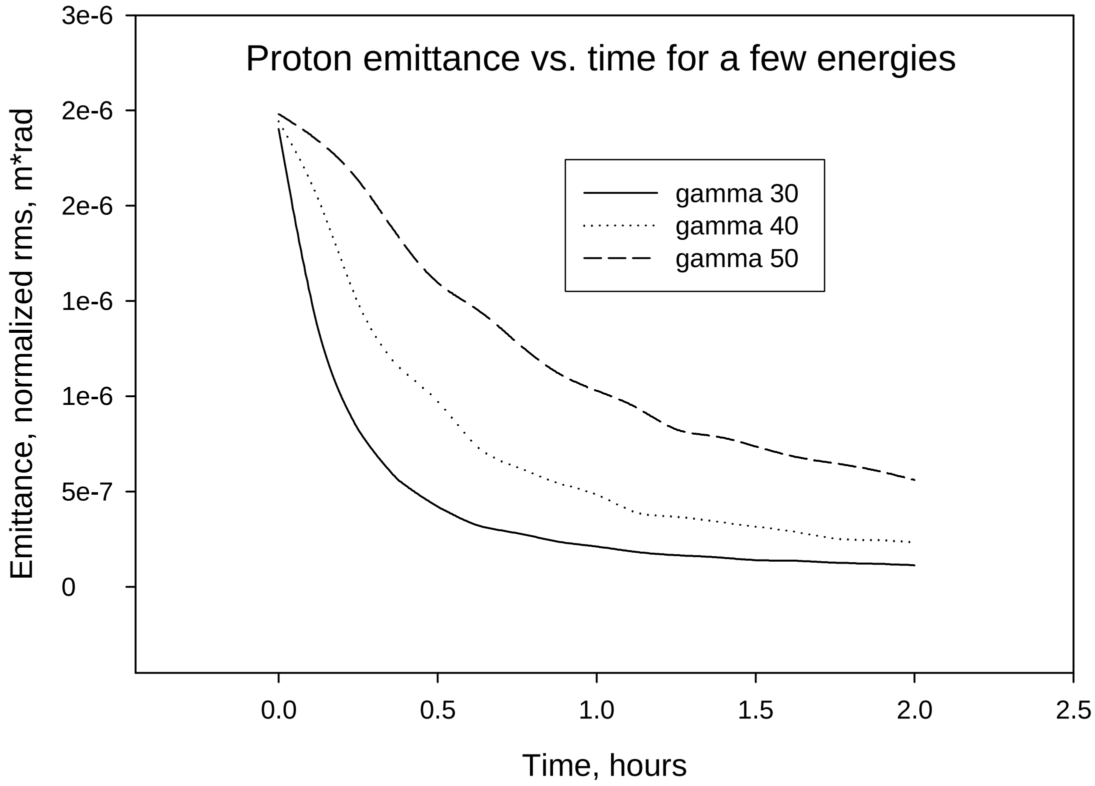
Gold ions per bunch vs. time, with and without cooling



Beam disintegration by collisions dominates!

Vasily Parkhomchuk

Cooling Simulations – SIMCOOL emittance for protons



Cooling Simulations – BETACOOL

- BNL is collaborating with JINR Dubna on the code BETACOOL.
- The new capabilities will include
  - arbitrary distribution functions,
  - improved IBS model
  - bunched beams
  - Longitudinal dynamics
  - Capability to simulate magnetic field error

Cooling Simulations - direct simulation

- D.L. Bruhwiler, R. Busby, J.R. Cary, D. Abell, P. Messmer, I. Ben-Zvi, A. Burov, RPAG045
- Coulomb collisions between electrons and ions will be simulated from first principles on a massively parallel computer.
- A slice of the electron beam is modeled, with a width on the order of the Debye length and periodic boundary conditions.

SUMARRY

- We plan for high-Energy electron cooling of the RHIC collider and future eRHIC
- The cooling system has new features
- A comprehensive R&D program is in place to investigate issues related to:
  - Magnetized beam generation, transport and acceleration with energy recovery
  - Electron cooling simulations
  - High-precision superconducting solenoid

Electron Cooling R&D Team, BNL Collider-Accelerator Department

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